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Automotive Seat Design and Collision Performance

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ALTHOUGH SAFETY IS A BASIC CONSIDERATION in all aspects of automotive engineering, it is a fact of life that safety advances are not uniformly accomplished. Some essential aspects of motorist protection have in the past, and probably will in the future, continue to be greatly outstripped by advances made in other areas. In some instances, the design challenge simply exceeds current technology; on other occasions an adequate safety standard and concerted industry interest can correct obvious safety deficiencies. For example, although improved tires resulted only after new materials evolved, a greatly improved motorist restraining system resulted from industry initiated research that culminated in a standard requiring installation of combination cross chest lap belts for all outboard front seat locations.

During the past 20 years, new materials and techniques have improved the comfort and wear resistance of automotive seats while simultaneously reducing their weight and cost; however, significant safety related improvement in seat design during this period has not been accomplished. A summary of findings from prior research (1)* published in 1966 classified a structurally redesigned Integral Seat with built-in S-point belt restraint as critically important for reduction of motorist injuries; this summary also pointed out the lack of safety-seat research up to that time. Although some research has been conducted since that time, the development of a safety seat still has not been accomplished. In the same study special devices, including the air bag, were rated as only of moderate relative importance.

After 10 years of government regulated safety standards and nearly that many years of intensive air bag development sponsored by both government and industry, the consensus of many automotive safety researchers in Europe (2), (3) and elsewhere is to change the emphasis back to development of active restraint systems and to increase effectiveness by means of mandatory use laws. Air bags, if used, would serve a supplementary function in conjunction with active systems. Progress in safer seat design has been impeded throughout a decade of automotive safety standard making, and many lives have been lost that could have been fully protected with a fraction of the inventive genius and funding lost to air bag development. A basic common sense approach to motorist protection from collision trauma calls for special attention to design of the critically important structure nearest the motorist, his seat.

A vital consideration of seat design is its capacity to protect motorists, to the extent practical, from all types of collision injury exposures. This paper provides basic design data for crashworthy automotive seat systems with integral active re-

*Number in parentheses designate References at end of paper.

ABSTRACT

Eighty-five laboratory full-scale force-deflection tests were conducted on passenger vehicle seats, foreign and domestic, for purposes of evaluating specific resistance to a collision environment and mechanisms of collision induced seat distortion. These tests evaluated seats that span the past thirty years; additionally, seat design studies were conducted evaluating basic features of automotive seating during the past eighty years.

Data from full-scale collision experiments and from a large number of actual accidents facilitated the establishment of seat design criteria for greatly improved collision performance. Evolution of seat and head support standards in the United States and Europe are presented with evaluation of their relative significance to the requirements of automotive seat collision performance.

The foregoing research provided foundation for modification of a production automobile seat into an integral safety seat, based on a design concept that minimizes bending moments during collision. The modified seat was subjected to the same laboratory test procedure applied to the 85 non-modified production seats and results of its performance is given.

Design concepts are presented that would serve to mitigate undesirable seat distortions during collision and thus improve seat restraint capabilities without compromising the important factors of comfort and cost.

straints, as determined from the authors' collision research and laboratory studies as well as experience gained from investigation of relevant accidents.

BACKGROUND

The first automotive seat, like the first automobile was an adaptation from the horse-drawn carriage. Springs to absorb road shocks were primitive, effective padding was non-existent and seat adjustability had not yet been considered. Commencing around 1900, motorist safety while travelling over rough roads was improved by development of deeply contoured seats that reduced the likelihood of motorist ejection as the car body pitched and rolled. Generally, however, little consideration was given for the safety of the occupants, Fig. 1.

Front seat fore-and-aft adjustment was not available until about 1929 when adjustable front seats for the driver became a feature of higher priced automobiles. Occupant comfort was given increased attention as engineering problems concerning motor vehicle performance and reliability became more effectively managed. Improvements in seat design continued and by the mid 1930's, seats, tracks and runners closely resembled those of the mid 1960's. During the period between the thirties and the sixties, the only significant innovation in seat design was the introduction of power seats and adjustable reclining backrests during the early 1950's, Table 1. Seatback height reached reasonable levels in the late 1960's but by the mid-seventies the height of backrests on many models had declined to levels less effective than thirty years ago. Seatback strength has not increased significantly over the past thirty years and remains inadequate to resist even moderate collision forces. The remarkable safety improvement facilitated by the backrest head support standard FMVSS 202 has been compromised through failure to upgrade criteria to maintain performance commensurate with intent. Seventy percent of adjustable head restraints are used in the downmost position (4). Little effective protection is afforded the motorist unless the head restraint is positioned behind or slightly above the head and remains in such support position during collision.

SEAT FUNCTION AND CONFIGURATIONS

It is not a simple engineering task to design a good automotive seat; it must provide comfort, style and safety, and yet be sufficiently light weight to facilitate vehicle fuel economy and to minimize collision inertial stresses. Seat designs and materials must be affordable and durable to give acceptable service over the life of the car. In addition to provisions for comfort and position adjustments, a seat also should have adequate structure for housing safety and convenience accessories. Trade-offs are imposed by this complex mix of requirements; however, in seat design we should no longer overlook the requirement for a reasonably safe, collision resistive structure with built-in active restraint system.

SEATING CATEGORIES - Automotive seats for passenger vehicles have a number of basic configurations and sizes depending on intended use and location. Position adjustment depends on factors such as location (front or rear): availability of comfort features, including center armrests, depends on vehicle price, type, purpose and country of origin.

BENCH SEAT - SOLID BACK - Standard and compact 4-door sedans are frequently equipped with solid-back bench seats, front and rear. The front seat has a single adjustment mechanism and the entire seat is usually adjusted according to the

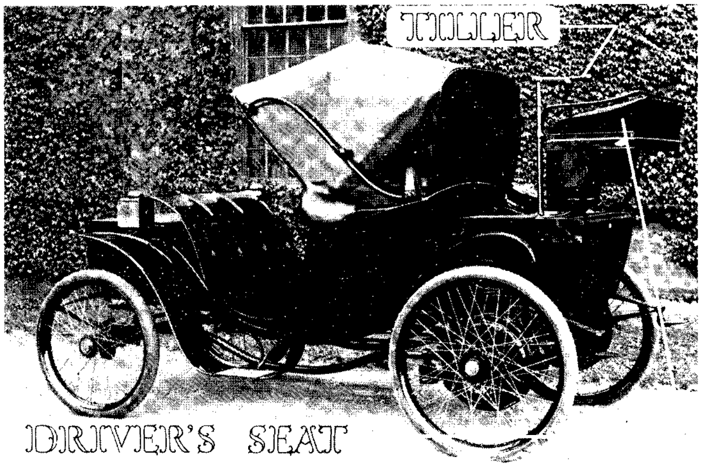

Fig. 1 - Driver's seat, horseless carriage

TABLE 1

SEAT DESIGN EVOLUTION

INTRODUCED	ITEM	EXAMPLE
1890 - 1900	Automotive Bench Seats	Philion*
1900 - 1910	Deep Bucket Seats	Thomas*
1910 - 1915	Fold-forward Backrests	Model-T Ford*
1910 - 1915	Console Between Seats	Wescott*
1910 - 1915	Pedestal Seat	Argo Electric*
1915 - 1920	Swivel Seat	Cole*
1920 - 1925	Fold-down Armrest	Dusenberg*
1925 - 1930	Fore-and-aft Adjustment	Viking*
1950 - 1952	Power Seats	Packard
1960 - 1963	Optional Head Restraints	All U.S.
1968	Integrated Head Restraint	Volkswagen
1969	Standard Head Restraints	All U.S.

*Based on authors' study of vehicles made available through cooperation of Harrah's Automotive Museum, Reno, Nevada.

needs of the driver. A bench seat, if adequately designed for three occupants, must be capable of sustaining a rearward static moment, calculated about the H-point of the seat, equal to three times that of a single seat.

BENCH SEAT - SPLIT BACK - Fold-forward backrests provide access to the rear seat of 2-door vehicles. Since only the upper portion of the seat is divided, the fore-and-aft adjustment can accommodate only one person. Backrest angle, however, can be made adjustable according to the individual needs of driver and passenger.

BUCKET SEATS - Contoured seats for individual occupancy are called bucket seats, although this term originally applied to more deeply contoured racing-type seats. The containment feature of deeply contoured bucket seats has been identified by the authors and others (5),(6),(7) as a consideration in design of a safer seat, owing to improved lateral retention; however, the extent of contouring must be based on consideration of comfort and practicality as well as safety.

Adustable backrest angle is commonly available and provides improved comfort and reduced muscle fatigue. Direct attachment to the seat of both lap and shoulder belts is a safety and convenience goal that has been identified previously, (1),(5),(6),(7),(8) and is further evaluated in this study.

FOLDING SEATS - These seats require special design considerations to allow them to be folded flat when hauling cargo. These requirements include special sizing, latching devices and flat, durable cargo surfaces. Seatback height and strength as well as provision for isolating cargo are collision safety factors to be considered.

PEDESTAL BUCKET SEATS - These seats are common to buses, vans, motor homes and trucks. In addition to the normal fore-and-aft position adjustments, variable backrest angle and swivelling mechanisms are sometimes provided. Because of their elevation, direct restraint system attachment requires special design considerations.

FIXED, BUS-TYPE BENCH SEATS - Although similar to the rear seats of passenger sedans these seats are elevated and generally provide open space beneath; structural limitations and remoteness of seat from floor increase the difficulty of direct restraint attachment. Seats used in buses that transport children require special considerations, (9), (10).

SEAT SYSTEM COMPONENTS

A brief description of seat components will allow a better understanding of basic seat requirements and the special seat structure necessary for adequate passenger protection from collision trauma, Fig. 2.

STRUCTURAL FRAME MEMBERS - The seat framework is usually constructed of steel that has been formed into tubular configurations or of stamped or rolled sheet metal. Historically, the function of this structural backbone has been limited to providing shape for the cushioning members and support for its own weight and that of its occupant. Redesign and strengthening of the seat framework in conjunction with its anchorages can provide the force resistance necessary for occupant restraint during moderate and severe front, side and rear-end collisions.

NON-STRUCTURAL SEAT MATERIAL - Cushions, springs and upholstery provide the necessary means of load distribution between occupant and seat frame; they also provide contour and geometry necessary for occupant comfort. A redesigned integral seat would include energy absorbing (E-A) padding at the sides, top and back to provide additional force moderation and load distribution during collision. This concept is typified by the Crandell-Liberty Mutual Survival Car II (11).

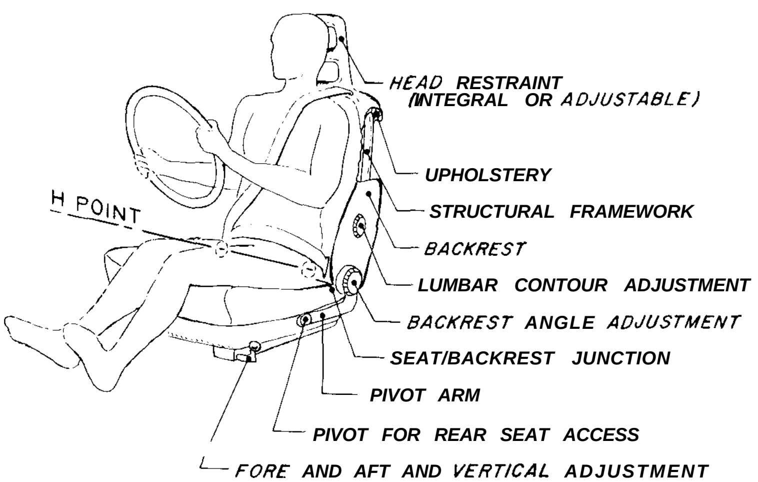

Fig. 2 - Seat nomenclature

SEAT ADJUSTMENT MECHANISMS - These mechanisms should be strengthened to withstand collision forces as well as the rigors of everyday usage. Considerations of driver anthropometric differences necessitate a multiplicity of seat adjustments to assure that a given seat provides the multiple functions of driver positioning for correct reach and view, as well as for adequate comfort. Desired seat position may be accomplished by means of longitudinal, vertical and tilt adjustments. Other adjustments include backrest angle, head restraint position and lumbar support stiffness.

Head restraint height adjustment is a common feature of current production seats. Unfortunately, many recent seat designs provide no head support protection from even minor rear-end collisions when the head restraint is in its most commonly used, retracted position. Proposed legislation (12) would modify head restraint requirements to ensure proper utilization by preventing mis-adjustment or complete removal. Backrests with integral head restraints eliminate adjustability deficiencies, but should be designed to protect 95th percentile adult male occupants. Adjustable headrests should extend to 80 cm (32-in) and not allow adjustment below 70 cm (28 in); the headrest in its adjusted elevated position must not collapse from head impact.

SEAT ANCHORAGES - Most vehicle designs depend on seat attachments at the floor or at the sill and tunnel to transmit forces between the vehicle and the seat. This anchorage is generally interposed between the seat adjustment mechanism and the vehicle floor pan or lower structure.

Under static conditions, the seat anchorage transmits compression, tension and shearforces from the seat to the floor or side structure. In the event of collision or handling accelerations, the resulting forces are transmitted in reverse direction from floor to seat. The seat anchorage structures and attachments require a design of adequate strength to accommodate seat and occupant inertial forces identified specifically in other sections of the paper. Besides the usual floor, sill and tunnel anchorages, other potential anchorage locations for strengthened seat systems include side and roof attachment.

SEAT DESIGN CONCEPTS

Restraint compliance, is the change in restraint geometry induced by motorist's inertial forces during collision. For example, a lap belt may initially course from its floor anchorage toward the lap of the wearer at 45 degrees but as a frontal impact develops, this angle is reduced owing to a combination of factors that result in the occupant's buttocks being compressed downward and forward on his seat as the belt restraining forces increase, (13). Similar ily , variations in support force, restraint angle and resulting backrest pressure modulations occur for the seated occupant as the seat backrest undergoes restraint compliance during a rear-end collision. This is illustrated for restrained and also for inadequately restrained occupants, by the geometric areas within the curves depicting displacements of occupants relative to their vehicle, Fig. 3. Also shown is the added physiological trauma associated with unstructured, inefficient restraint compliance. Variations in occupant collision-induced accelerations (slopes, Fig. 3) depend on the effectiveness of occupant restraints which determines in large measure the trauma during ride-up/ride-down accelerations; the mechanism of transmission of accelerative forces represent the other operative factor for such traumatic exposures. The problem faced by a seat designer is to determine the force resistive levels, and therefore the degree of collision severity, a specific seat design should be able to accommodate before back-

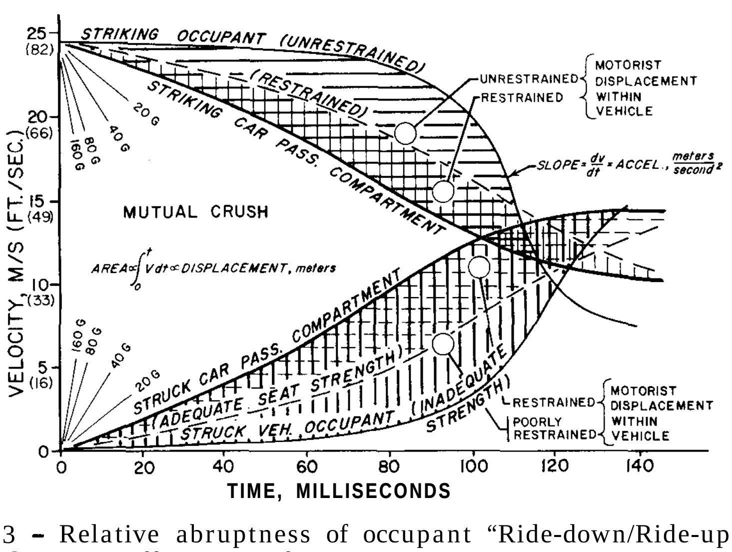

Fig. 3 - Relative abruptness of occupant "Ride-down/Ride-up ," according to efficiency of restraint

rest restraint compliance reaches values where occupant forced displacements expose him to serious or critical injuries.

When not faced with the realities of cost and operational practicality, as well as the need to provide design features that favor public acceptance, a simplistic approach is to set safety design criteria at some arbitrarily high level, one considered sufficient to encompass virtually all probable collision exposures. Such arbitrary criteria is insensitive to orders of priority and cost for safety design improvement and disregards the interactive response it may impose on other related, or concurrently important, passenger and operational safety features.

The front seat backrest and the steering column have in common the engineering design problems that result from dealing with cantilevered structures acted upon by occupant collision forces. Additionally, backrest angles of 15 to 25 degrees increase design difficulties by incorporating angles that allow less efficient crash force moderation.

LABORATORY SEAT TESTS

Passenger vehicle seats of differing make vehicles are as varied structurally as the motor vehicles within which they are mounted. Aside from their apparent commonalities consisting of seat, backrest, head support, covering, padding, springs, and frame, the multiplicity of design and size variations account for their significantly differing weights (under 9 kg to over 45 kg or about 20 to over 100 lbs.) height of backrests (from 51 cm to about 76 cm or from 20 to about 30 in) and maximum bending moment before excessive backrest deflection (from 45 m-kg to about 95 m-kg or about 4000 in-lbs to 17,000 in-lbs), Fig. 4. As remarkable as these variations would appear, they represent little difference in motorist protective capacity owing to the fact that none of them are capable of effectively resisting motorist inertial forces for any substantial impact exposure.

Based on laboratory tests of seats from cars large and small, foreign and domestic, and from vehicles 30 years old to near new, backrest strengths were found to be remarkably alike, Fig, 4. Force-deflection performance curves of representative production seats as well as recommended performance for passenger vehicle seats capable of protecting their occupants during severe collisions are shown, Fig. 5.

INTEGRATED SEAT - The concept of an integrated seat for motorists has been considered and evaluated theoretically; experimental seats have been constructed and tested experimentally, (1), (2), (5), (6), (7), (11), (14). In general, the approach has been to design an entirely new seat, inducing the argument that practical aspects of manufacturing, occupant comfort and similar design burdens remain yet unsolved. With this in mind, the authors redesigned a Volvo production bucket seat into an integrated safety seat. This approach should facilitate recognition by automobile manufacturers and the Federal Government's safety standards making authority, that the goal for greatly improved motorist safety is reasonably attainable through development of an integrated front seat.

The Volvo seat was stripped of its upholstery and subjected to an evaluation of modifications considered essential to developing performance specifications for an integrated safety seat, Fig. 6. Next, this production seat frame was modified to provide the added structural support required for the special protective hardware, Fig. 6b.

Seat Modifications - Changes were made in the production seat by additions of components to augment existing safety and comfort features and to introduce new protective functions as follows:

(a) High section-modulus tubular steel backrest, from seat attachment through head support.

(b) Double seat tracks, for more positive anchorages.

(c) Lap and cross-chest safety belt inertial reels mounted to seat frame for ease of fastening and for optimum occupant restraint for all adjustment positions.

(d) Energy absorbing back panel, to moderate and pocket occupant inertial loads during medium and high-speed rear-end collisions and to provide knee pocketing for kinematic control of rear seat occupants thrown forward during frontal collisions.

(e) A pair of seat-mounted inertial reels for belt fabric which connects the base of the seat at its rear to the roof; the belt fabric is passed through the backrest to the roof anchorage. This arrangement allows the seat to be adjusted fore-and-aft and folded for entry accommodation; however during a front or rear-end collision, the dual "safety belts" are capable of immediate seat inertial snubbing.

(f) Deeply contoured bucket seat geometry to assure occupant positive lateral support and to improve comfort.

(g) Retention of the most advanced comfort and safety features of backrest angle adjustment, lumbar spine firmness adjustment and louvered see-through head restraint.

Most prior integrated seat concepts have utilized the backrest cantilever principle which necessitates strengthening floor and seat anchorages along with seat and backrest framing in an effort to combat the extreme bending moments, especially attending front and rear -end collisions, (7), (8), (14). The advantage of this approach is that seat fore-and-aft positioning and backrest folding for access to the rear seat can be accommodated without roof or side attachment; disadvantage is that

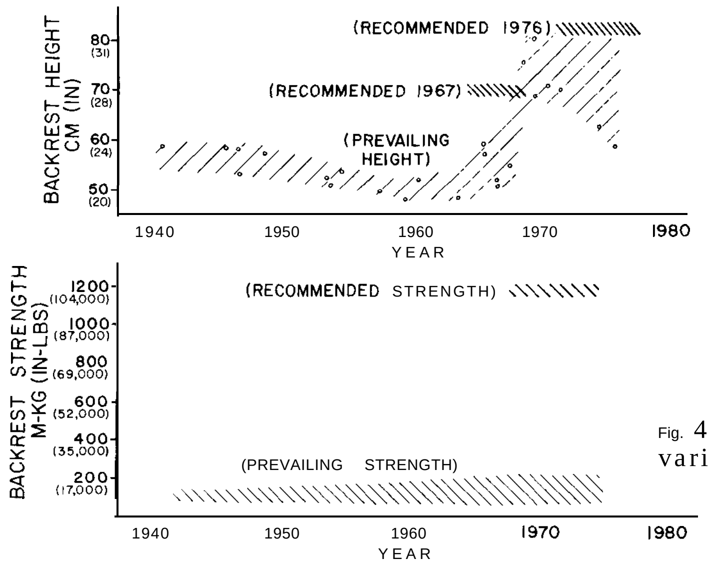

Fig. 4 - Automotive seat strength and backrest height variations over the past thirty years

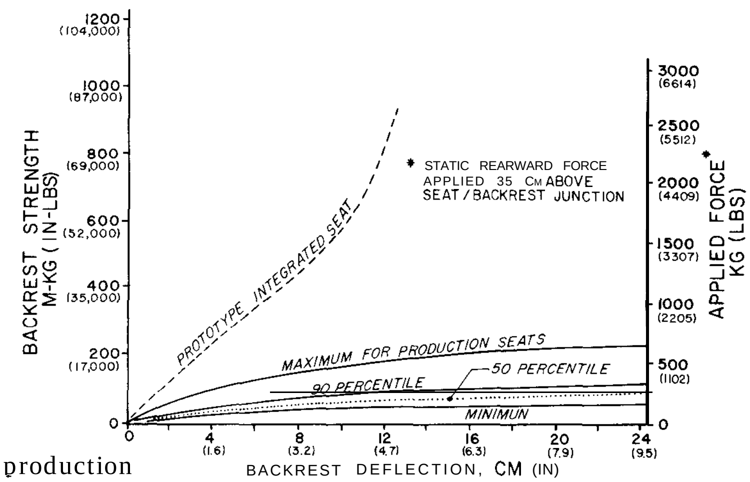

Fig. 5 - Backrest force-deflection data for 85 production automobiles, foreign and domestic, large and small sized vehicles

it is a very inefficient method of resisting large forces owing to the massive increases in structure required to offset extremes in bending moments. The authors found that many production seats could resist between 900 and 1800 kg force (about 2000 to 4000 lbs) horizontally rearward or forward at the seat rail. If these floor anchorages were only slightly improved, and connected by belt webbing to the roof, the cantilever design could be replaced by the basically greater efficiency of the tension semi-hoop design spanning floor to ceiling. The Experimental Safety Vehicle by Opel also uses a form of roof anchorage for its front seat backrests, (2). Encouragement was given to the practicality of this concept by a preliminary test of roof strength of a mid-sixties 2-door hardtop sedan. This unmodified roof structure withstood over 1800 kg (4000 lbs) horizontally rearward at a localized backrest to roof attachment location, without significant downward crush.

The integrated seat was subjected to laboratory tests along the lines previously described as shown by Fig. 8. The improvement in force-displacement over non-modified production seats is shown by the dotted curve of Fig. 5. Considering the nature of changes necessitated by using an existing seat, it is apparent that a somewhat lighter seat could be made even stronger if it were an original design rather than a retrofit. The composite design factors for a remarkably stronger, attractively contoured seat are shown by Fig. 7. Extensive crash testing of such new concepts are recommended for sound development before they are used in production vehicles.

SEAT COLLISION PERFORMANCE

Relative to vehicle safety, performance connotes a level of attainment, a plateau from which concepts for improvement may be assessed, both as to practicality and possible adverse influence on other safety requirements. Like the occupant that uses it, a

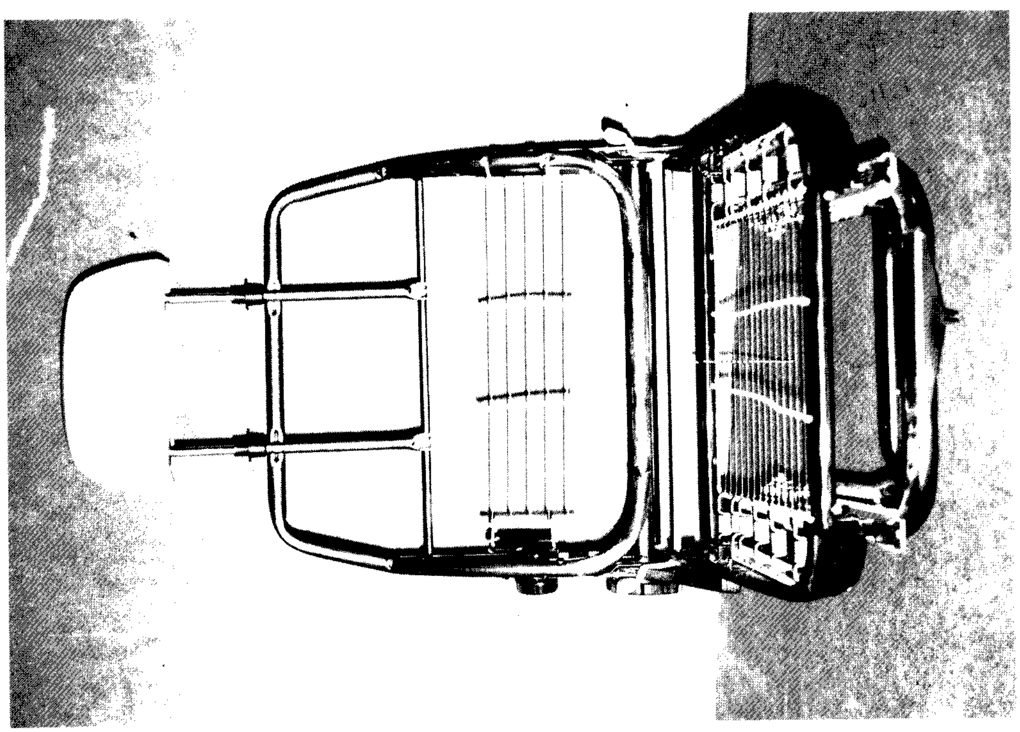

Fig. 6A - Volvo production passenger car seat frame, modified to high-performance integral safety seat

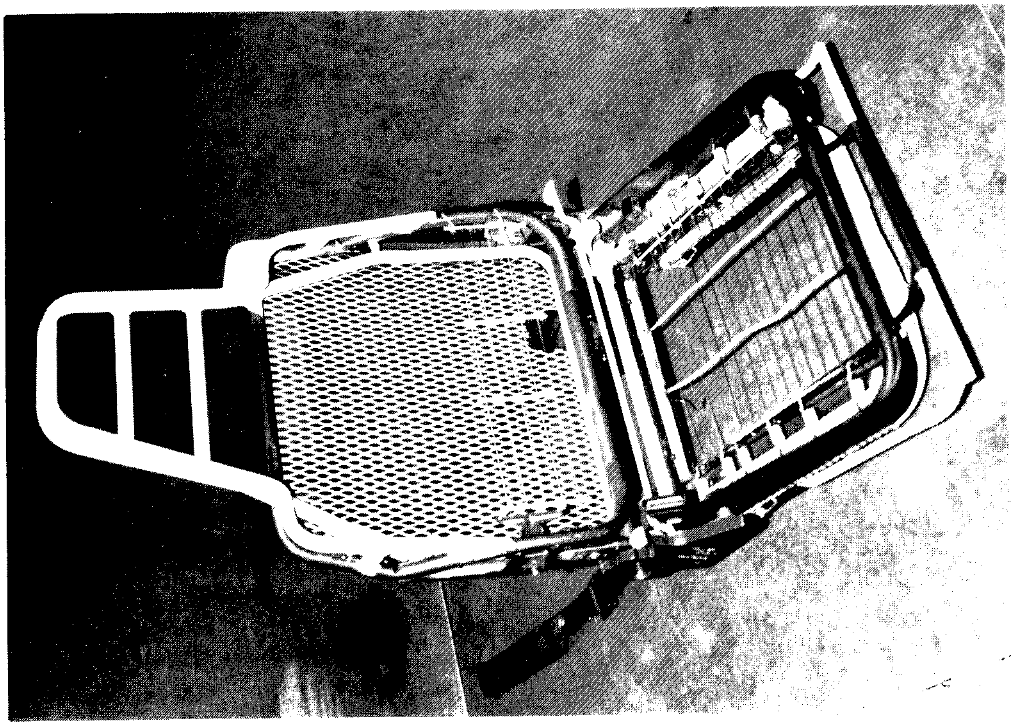

Fig. 6B - Volvo production passenger car seat frame, modified to high-performance integral safety seat

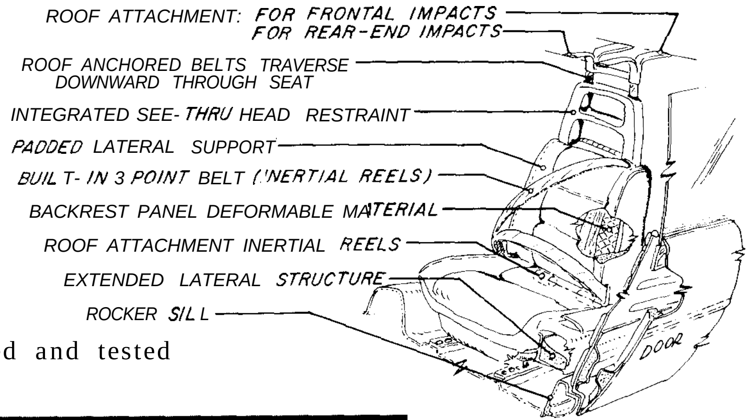

Fig. 7 - The Integral Safety Seat conceptualized and tested by the authors

Fig. 8 - Integrated seat during testing; 2268 kg (5000 lb) force applied rearward

seat has rather specific collision force tolerances: exceeding its design criteria allows crash forces to yield or fracture whatever component of the seat is most susceptible. This collision response is common to all seats, as determined from destructive tests to over 85 different automobile seats mounted on their floor pans. Although individual designs determine which components may fail first, their level of susceptibility is remarkably similar. Perhaps the foundation for this similarity in seat strength levels is generic to the basic design requirements that were dictated long before collision forces were identified as factors for consideration. For example, an adult male can apply 90 to 135 kg (200 to 300 lbs) force to the backrest during emergency braking. If passengers also brace for a possible collision, the backrest of *a* bench seat can be called upon to resist as much as 275 kg (600 lbs) force, It is understandable, therefore, that seats in the forties and fifties had backrest yield resistance of about 275 kg (600 lbs) even though they were not designed in a period when collision safety was a prominant consideration: incomprehensible is the fact that seats in the seventies show no significant improvement.

The basic collision performance criteria that applies to a seat is its resistance to backrest yield and its ability to transmit forces through the seat to its anchorages. Although seat design has in no way kept pace with advances made in other safety related areas, there are some notable exceptions; certain Mercedes and Porsche automobiles, for example, attach lap belts to the seat, rather than using the less satisfactory arrangement of floor anchorages. Volvo and Saab have provided see-through head restraints that improve visibility. The track record of most vehicles, however is not impressive. In general, backrest strength and height has not improved, possibly because the need for stronger, full-support backrests is not fully understood by regulatory agencies and those making design decisions.

SEAT COLLISION PERFORMANCE - FRONTAL COLLISIONS - It is becoming increasingly apparent that passive restraint systems alone cannot protect motorists from the varied exposures encountered during motor vehicle accidents (2), (3). Systems that protect during a barrier-type crash may be completely ineffective if the same frontal collision is accompanied by one or more minor impacts or an upset. The cross-chest lap belt restraint system, on the other hand, provides effective motorist protection during most collisions or combinations of collisions, including upset. If an integral three-point restraint system is available, in conjunction with the strengthened seat to which it should be attached, it can provide levels of protection unattainable with any other single system, however costly or complex. In addition to minimizing or eliminating impact forces to the vehicle interior, the combined restraint system appreciably reduces the forces that would be applied for a lap belt only protective system, (15).

One advantage claimed by air bag proponents is the additional ride-down distance provided as the motorist crushes forward relative to the vehicle interior. Direct attachment of belt restraints to the seat minimizes uncontrolled belt slack and at the same time allows the designer to incorporate belt pre-stressing and other ride-down improvements for the belt and seat anchorages. The belt system can thereby provide maximum protection for front-end collisions and also provide more adequate protection during the wide range of other collision exposures, including moderate to severe rear-end collisions by keeping the occupant in the seat. Even a floor mounted lap belt can provide considerable protection under these conditions, (16).

Rear seat occupants that fail to fasten their belt would obtain some degree of passive restraint from a strengthened front seat backrest. The knee pocketing concept evaluated and described previously (6), will add considerably to rear seat occupants' collision protection by controlling posture during their "second collision." The spacing between rear occupants and front backrest provides a time delay before the rear occupants strike the front backrest; therefore, front seat occupant ride-down would not be compromised significantly from subsequent impact to the backrest by the rear seat occupant. Rear seat occupant protection for all but rear-end collision exposures can best be accomplished by means of active restraint systems.

OCCUPANT RESTRAINT WITH A RECLINED SEAT - The cross-chest lap belt is less effective in front-end impacts where the passenger has reclined his seat; the torso slides forward, shifting the lap belt upward across the viscera. When belt snubbing eventually occurs, forces are transmitted to portions of the body unable to sustain them without exposure to serious injury. Also, the neck or head may strike the cross-chest belt in an ineffective, if not dangerous manner. One solution is to provide an additional pair of straps attached at the front of the seat and passed upwards through positioning guides. Before reclining the backrest, the hanging ends of the straps are pulled up between the legs and fastened to attachment loops sewn to the lap safety belt. This arrangement maintains the lap belt across the pelvic girdle during collision and, for non-integral seats, reduces mal-alignment of the cross chest strap as the torso flails forward against it.

SEAT COLLISION PERFORMANCE - REAR-END COLLISIONS - The most frequently occurring type of motor vehicle collision is the rear-end impact. For example, forty-nine percent of the 14.6 million accidents involving motor vehicles in the United States during 1968 were same direction or rear-end type accidents; representing nine percent of the total number of fatal collisions, (17).

Seat backrest performance during rear-end collisions parallels a condition of walking on thin ice; minor torso inertial forces receive adequate support but as impact severity increases, the resistive support approaches negligible values. The mechanism by which this passive restraint is lost is generally unimportant insofar as its effect on motorist kinematics is concerned. Torso inertial movement does not respond differently with differing mechanism of loss of back support; it simply responds inertially to fall-off of resistive force. Thus, whether backrest resistance is subsequently lost because of excessive backrest yield or by combinations of backrest yield and anchorage separations, the motorist inertial forces will act in the same manner.

Backrests are slightly reclined for comfort and to assist with torso support. However, as the seat is forced to recline additionally during rear-end collision, the torso is predisposed to ramping up the plane of the backrest, Fig. 9. On reaching backrest angles exceeding 45 degrees, the ramp component falls off according to the function "$\sin\alpha \cos\alpha$," where alpha (α) is the backrest angle rearward from the vertical axis. Simultaneously, the backrest support force, F_{SB}, which accelerates the motorist as the backrest bears against him during a rear-end collision, falls off as a function of backrest yield-angle, likewise depicted by Fig. 9. Obviously, a zero or near zero angle provides the most effective torso support by the backrest during rear-ending and torso support tends to fall off thereafter, as a cosine function of increases in the backrest angle.

These factors are particularly relevant for production seats involved in light to moderate rear-end collisions where backrest strengths generally are adequate for those respective exposures. However, for most moderate to severe rear end collisions, all production seat backrests deflect to angles providing no effective motorist support. This situation is illustrated by considering the relationship of backrest support provided the torso as a function of rear-end collision speed, Fig. 10. Sixty-five percent of the body weight may be used

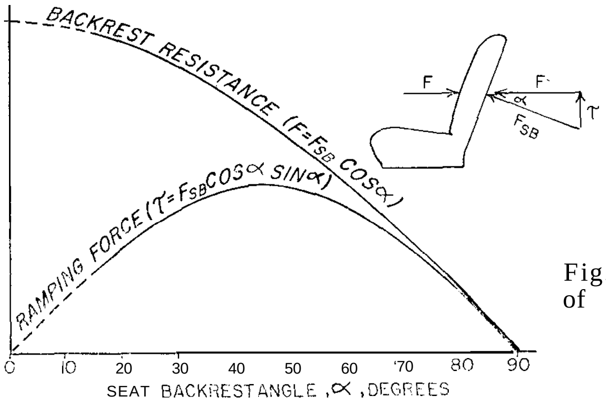

Fig. 9 - Degradation of backrest support as function of collision induced deflection

as a minimal approximation of the torso and adjacent flailing body components that operate any instant to inertially act on the backrest and may be characterized as the occupant inertial force, F_{OI}. The seat backrest yield point, or point of maximum backrest resistive force, F_R, is reached when the occupant inertial force plus the seat backrest inertia force exceeds FR as shown by $F'_{OI} + F_{SI} = F_R$. Based on collision experiments (14) the torso inertial force increases with collision speed, in the manner shown by Fig. 10. Regardless of speed of impact, the backrest can provide only a given maximum resistance to yield; however, as rear-ending speeds increase, the collision severity is reached where the backrest can at best support solely its own weight, but none of the occupant, Fig. 10. Thus the effective backrest strength is dependent on a combination of backrest resistance to yield and backrest weight, referred to as backrest weight, referred to as backrest inertial yield resistive force. The lighter the weight of a seat, relative to a given resistance to deflection, the better able the seat to resist torso displacement during rear-end collision.

Given a sufficiently severe collision, any seat will fail; the type of failure however, depends on design. Rear-end collisions induce five basic types of failure; a particular collision exposure for a particular seat design may result in one or a combination of these five types of failure:

(a) Excessive backrest yield
(b) Track-runner vertical separation
(c) Track-runner longitudinal separation
(d) Compressive crush at seat base
(e) Floor yield at seat attachment

All automotive seats have collision induced failure modes that are caused by moments and forces exceeding one or more of the seat component yield points. Critical reaction requirements can be calculated for various occupant sizes and acceleration exposures using free body analyses of the seat system, Fig. 11.

For rear-end collision exposures, the addition of a roof anchorage for the backrest serves to distribute forces and considerably lessens design requirements for individual components. For example, the extremely difficult design task of providing 75,000 inch-lbs yield resistance at the backrest pivot for a 50% adult male in a 30G seat system can be easily managed by utilization of a roof anchor. If one-third of the 6540 pound horizontal force is applied at the top of the seat and acts 32 inches above the backrest pivot, we now have the following moment at the pivot arm:

MI = 75,000 - (32) (2180) = 5300 in-lbs, a reduction to 7% of the original required bending moment. Most production seats can provide this level of bending resistance without need for modification. With a roof attachment, the maximum bending moment will be at a higher elevation on the seat and in a location of the backrest free of complications of pivots and adjustment mechanisms. Correspondingly, the reduction in reaction strength required at R_R, RH and R_F, if a roof anchorage is added, provides a requirement of only 2%, 65%, and 2% respectively of the values necessary without a roof attachment.

SEAT COLLISION PERFORMANCE - SIDE IMPACTS - Direct side impacts into the passenger compartment represent the gravest danger to motorists at a given speed of impact for any type of collision, (18). Usually less than a foot of intervening structure, much of which is non-structured space, separates the motorist on the impacted side from the front end of the impacting vehicle. During collision, the near-side occupant suffers a considerably more severe acceleration than does the vehicle in which he is riding. This impact exposure can be lessened somewhat by increasing the amount of side structure stiffness and thereby minimizing passenger compartment intrusion. However, the point of diminishing return is soon reached as intervening structure is added, since crush distance is still limited, and delayed occupant response serves to magnify the resulting exposure, A considerably simpler solution is to attach the motorist firmly to a deeply contoured seat by means of an integral 3-point belt and to provide intermediate structural members between striking car and seat to cause the seat,

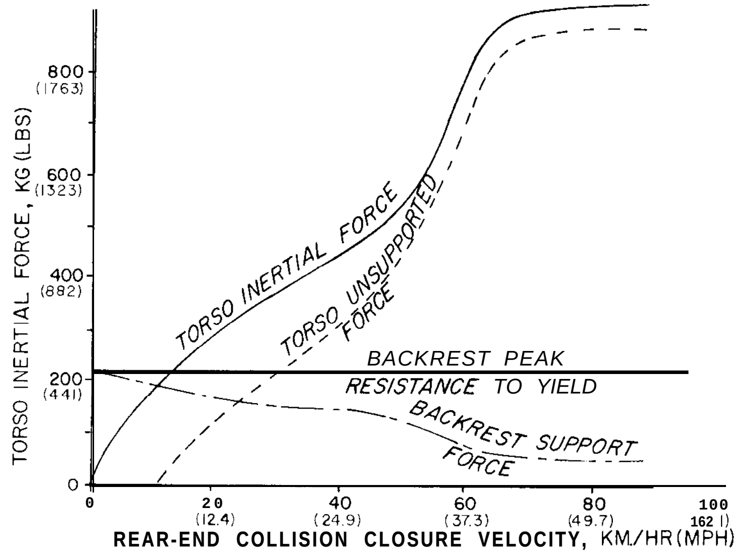

Fig. 10 - The relationship of backrest torso support, as a function of rear-end collision speed

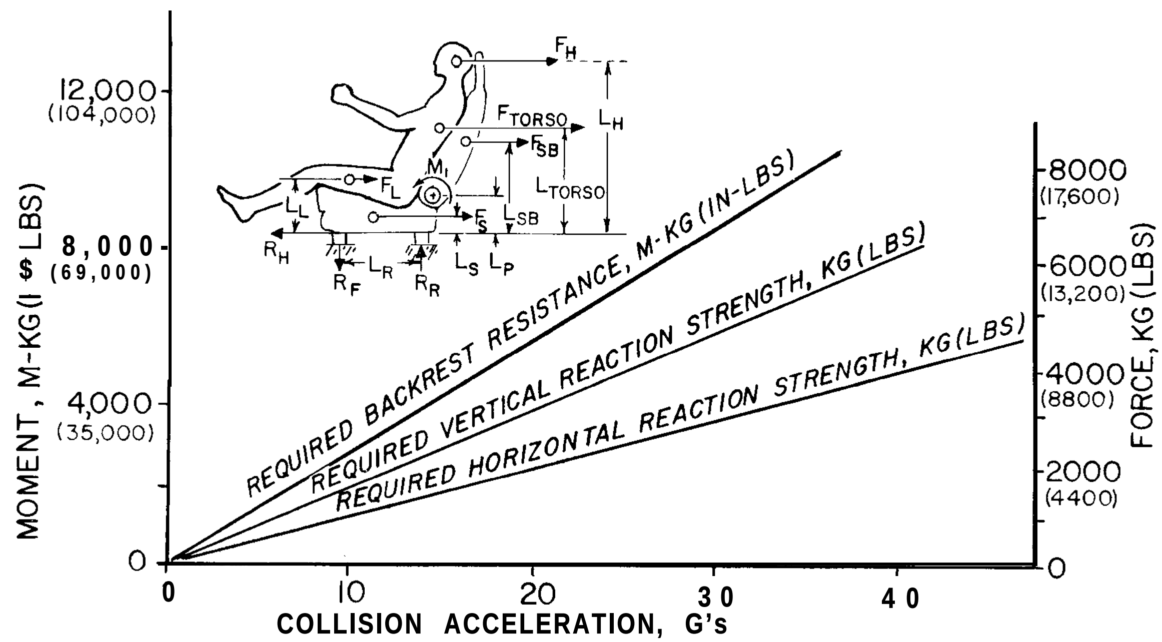

Fig. 11 - Collision induced seat stresses, rear-end collision exposure

with occupant attached thereto, to be accelerated more promptly but less abruptly.

Analysis of the velocity-time profile of a typical side impact collision, Fig. 12, provides further understanding of the nature of accelerative exposure and resulting injury mechanism as it exists for the unrestrained struck motorist. This graph also shows the remarkable reduction in occupant acceleration that can be accomplished if the seat is structured and interlocked with side panels so that it is accelerated more promptly following initial contact by the striking vehicle. This improved side impact acceleration, or "ride-up," is similar to the "ride-down" concept of protection from frontal collisions, identified by prior publication, (19). The more prompt acceleration also reduces the impact abruptness or "Stapp"-factor. Since the combined weight of the seat and the occupant is often less than 90 kg (200 lbs), it is not necessary to provide significantly heavier structure than already present to accomplish the objective of prompt seat acceleration during a collision. It is only necessary to position the structure at the proper elevation and location to allow more direct collision force application to the seat structure to occur before substantial in-

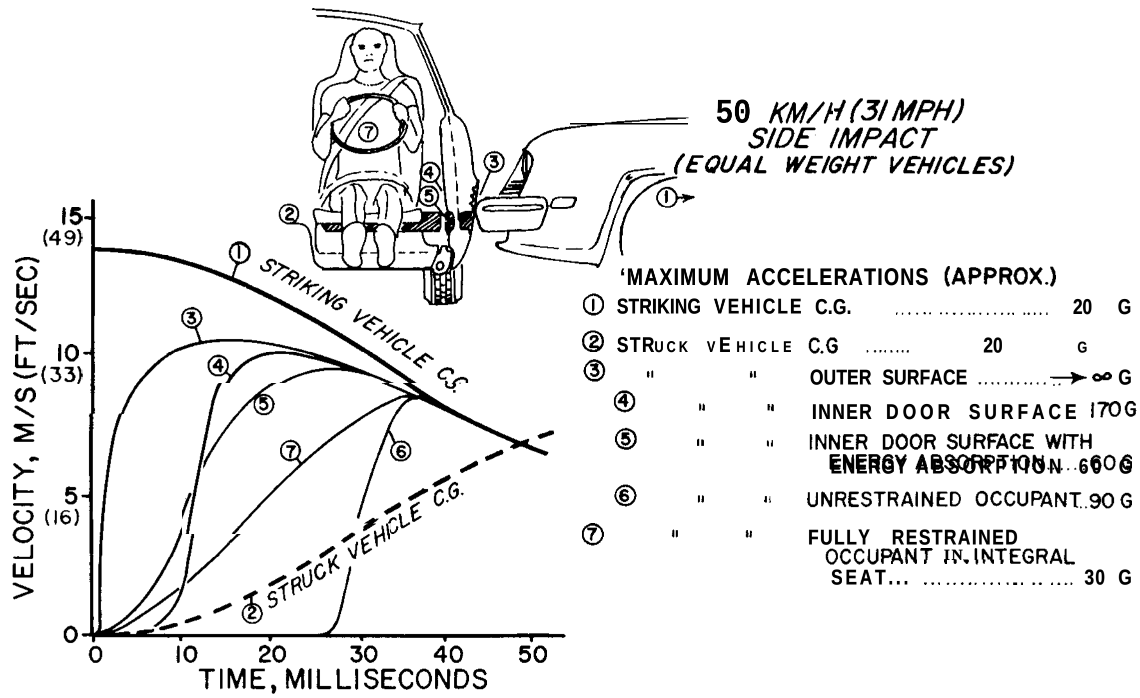

Fig. 12 - Integral seat, side-impact exposure analysis

ward crush has taken place. Additional motorist force moderation is provided by the pocketing effect of the integrated seat. This seat side-structure tends to shield the motorist from direct impact by his vehicle side structure as well as to minimize "slack" between the motorist and his restraint system. This shielding also reduces motorist exposure to punctures and shear forces.

ROLLOVER PROTECTION - Injuries and fatalities during rollover accidents occur most frequently as a result of ejection (20), (21); a basic requirement for occupant restraint systems is to retain the occupant within the vehicle during upset. Even if adequate retention is achieved, protection is compromised if there is inadequate supportive roof structure.

Roof structures are sometimes flattened during upset sufficient to dangerously reduce the motorist survival space. This crush can be reduced considerably by constructing the seat backrests with sufficient strength to act as central pillars for the roof. A strengthened seat with integrated head restraint of a height necessary for adequate head support for taller persons 80 cm or more (32 in) is recommended if central roof collapse resistance is to be increased by backrest structural support. Seat backrest structure of sufficient strength and height to answer the requirements imposed by other collision exposures will also prevent complete collapse of roof structure in nearly all collision exposures.

STANDARDS AND RECOMMENDED PRACTICES

In November 1963, a Society of Automotive Engineers Committee report on passenger seats and adjusters was approved. This action, for the first time, extended the concept of recommended practices and performance standards to include automotive seats. Two tests were specified by recommended practice J879, the first of which established minimum strength requirements for horizontal inertial seat loadings for front and rear impacts. This 20G specification corresponds to approximately a 900 kg (about 2000 lbs) seat anchorage loading for a typically large domestic bench seat and serves to evaluate the retention capability of the adjuster mechanism and seat anchorages. The second test prescribed by SAE J879 concerned backrest strength and specified a minimum moment of 4250 in-lbs. Although the scope of the recommended practice included an intent to submit it to a "continuing review" no substantial changes were made until July 1968.

In 1965 the Federal Register published General Services Administration (GSA) Federal Standard 515-6 governing "Anchorage of Seats." This initial seat standard became effective in 1966 for 1967 model automobiles. GSA adopted basically the original SAE recommendations with no major changes. Although this transfer of J879 from an SAE Recommended Practice to a GSA standard was applicable only to government purchased vehicles, it was understood to be the forerunner for a standard directly affecting every passenger car sold in the United States.

In 1966, by act of Congress, the Department of Transportation (DOT) was added to the Federal Government. The 1965 GSA 515-6 Standard, which was actually the SAE Recommended Practice of 1963, was adopted by DOT in January 1968 as Federal Motor Vehicle Safety Standard (FMVSS) 207. The FMVSS 207 established backrest strength for standard passenger vehicles at 3300 in-lb, differing insignificantly from the GSA/SAE 4250 in-lb value, owing to a change in reference systems. FMVSS 207 references the Hip Pivot or H-point (as described by SAE J826b) whereas the SAE J879 and GSA 515-6 used a reference pivot point that was about 20 cm lower (8 in) at the interface between the seat frame and adjuster. Although 3300 in-lbs may appear to be an impressive value, production seats from the nineteen forties and fifties tested by the authors were found to substantially exceed this standard. FMVSS 207 included the requirement that the fold-forward backrest locks withstand a 20G minimum inertial load which represented a modest improvement. In 1972, FMVSS 207 was amended to include multipurpose passenger vehicles, trucks, and buses. Additionally, the standard was expanded to include requirements relating to rear seats.

Head restraints, whether separable, or integral with the front seat backrest were regulated by FMVSS 202 in 1969. This standard requires the head restraint to be capable of resisting a 200 pound force applied horizontally to it and actually consists of a more severe loading to the backrest pivot than does FMVSS 207, to reduce the chances of head support failure before backrest failure.

In Europe, seat strength standards applicable to non-exported vehicles were enacted by the Council of European Communities in 1974; these are basically the same as FMVSS 207, except for an increase in the minimum moment resistance of the backrest from 3300 in-lb to about 4700 in-lb (54 m kgf), both with respect to the same H-point reference.

Prior to the advent of the automotive standards making authority by the Federal Government, the automotive industry was largely self-governed, relative to implementation of safety concepts. Slow, methodical but nevertheless significant progress was made during this self-governed period, as pointed out in a prior publication, (19). The emphasis was on operational and performance safety; accordingly, collision safety advances were limited.

Following the mid-sixties, the responsibility for progress in collision safety was taken over by the Federal Government and assessment of the progress made in this more recent period depends on the specific safety category being considered. In general, commendable improvement in collision safety has occurred during this period of regulation by the National Highway Traffic Safety Administration (NHTSA). However, with respect to automobile seat collision safety, little progress has been made. A near obsession with air bag development regrettably has diverted a tremendous amount of research time and resources from the readily achieveable goal of making the automobile seat crashworthy. As a result, many automobiles being manufactured a decade after the onset of Federal Government standard making still have seats no stronger than they were during the pre-regulatory period. Any real improvements made in seat design have been on the initiative of the manufacturers because the seatback standards relating to strength have remained virtually unchanged. The presence of an inadequate, seldom upgraded standard limits initiative of automotive manufacturers because of the implication that satisfactory conditions prevail.

SUMMARY OF FINDINGS

1. Improved automotive seat systems should provide adequate structure and built-in active restraints to insure a reasonable degree of protection from collision forces. Seats need adequate contour to provide effective support and sufficient adjustments to meet the varied and changing requirements of their occupants. Redesign and strengthening of the seat framework and anchorages is required for direct attachment of lap and shoulder belts and to provide the force resistance necessary for occupant restraint during moderate and severe front, side and rear-end collisions.
2. All automotive seats develop collision-induced yield or separation modes caused by forces and moments from motorist and seat inertia when such stresses exceed one or more of the seat component yield points. Although the specific component of a seat that fails first may differ, the degree of susceptibility of all seats is remarkably similar. Laboratory tests establish that production seats from cars large and small, foreign and domestic, and from vehicles 30 years old to near new, have backrest strengths remarkably alike. All are incapable of effectively resisting motorist inertial forces for any but light impact exposures without inducing excessive yield and/or component separation.
3. Variations in support force and restraint angle occur for the seated occupant as the seat backrest undergoes restraint compliance during a rear-end collision. The mechanism by which this passive restraint is lost is generally unimportant insofar as its effect on motorist kinematics is concerned. Torso inertial movement does not respond differently with differing mechanism of loss of back support; it simply responds inertially to the degradation in resistive force.
4. Intended headrest height requirements are not met for many seats when the headrest is in its

most commonly used, retracted position. Backrests with integral head restraint should protect 95th percentile adult occupants; it is preferred that headrests be contiguous with the backrest and of fixed elevation; if adjustable, headrest adjustment should provide extension to 80 cm (32 in) and not allow adjustment below 70 cm (28 in).

5. Passive restraint systems that effectively control motorist collision dynamics during a barrier crash may be ineffective if the same frontal collision is complicated by multiple impacts or upset. The cross-chest lap belt restraint system, on the other hand, provides effective motorist protection during most collisions or combinations of collisions, including upset.

6. Collision-induced occupant accelerations vary according to the effectiveness of occupant restraints. These variations in "ride-up" and "ride-down" velocity changes determine in large measure the extent of trauma during collision; the mechanism of transmission of accelerative forces represent the other operative factor for such traumatic exposures.

7. The authors designed, constructed and laboratory tested a high performance integral safety seat that was made by structurally modifying an existing production seat design without compromising its advanced design comfort features. The roof-to-floor anchored webbing for backrest crash force attenuation remarkably simplifies seat structural requirements because bending moments are decreased more than ten-fold. By use of inertial reels this front seat conversion is accomplished without inhibiting rear seat access for two-door vehicles or backrest reclining or seat fore-and-aft positioning. Direct attachment of cross chest, lap belt restraints to the seat minimizes uncontrolled belt slack and allows incorporation of belt prestressing and other restraint compliance improvements. Increased costs for this restraint system concept would be nominal considering the benefits, however extensive crash test evaluation of any safety seat design is required prior to production to make certain all safety design features act constructively without degrading other aspect of motorist's safety.

8. The integral safety seat provides the basis for effective protective measures against direct side-impact collisions. With the motorist comfortably restrained by a 3-point belt and seated within a deeply contoured seat, structural members between the seat and outside door surface act, during collision, to accelerate the seat, with occupant attached, during the initial contact and crush phase of the collision and therefore accelerate the motorist less abruptly. Additionally, this design minimizes "slack" between the motorist and his restraint system and shields him from direct puncture and shear forces.

9. The integral safety seat protective capability against frontal impacts is well established, and roof crush during rollover can be considerably reduced by taller and strengthened front seat backrests serving as central pillars for augmentation of roof support: with an integral seat-restraint system, regardless of the direction of impact, levels of motorist protection can be achieved that are unattainable with any other single system, however costly or complex.

10. Commendable improvement in collision safety has occurred during a decade of regulation by the National Highway Traffic Safety Administration. However, with respect to automobile seat collision safety, effective progress has been negligible. A near obsession with air bag development regrettably has diverted a tremendous amount of research time and resources from the readily achievable goal of making the automobile seat crashworthy. Although the 3300 in-lbs backrest resistance feature of the FMVSS 207 sounds impressive, production seats from the nineteen forties and fifties tested by the authors were found to substantially exceed this 207 principal criteria.

11. Judged on any rational basis, whether as to initial cost, maintenance costs, functional reliability, exposure to dangerous malfunction or lack of effectiveness for many types of collision exposures, the air bag comes up as a king-size loser when compared with the collision protection of the integrated seat which includes integral cross-chest lap belt restraint. While the United States endlessly ponders the air bag issue, the rest of the automotive world has reached the conclusion that cross-chest lap belts in combination with mandatory use laws represents the simplest, least costly and most effective motorist protection measure.

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